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Wide-range bioelectrical impedance analysis circuit with GIDL-controlled ultrasmall current and ultralow frequency square wave generator

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Abstract

This paper presents an area efficient and wide-range bioelectrical impedance analysis circuit with GIDL-controlled ultrasmall current and ultralow frequency square wave generator. By using a gate-induced drain-leakage current (GIDL), we designed an ultrasmall current generator and an ultralow frequency ring-oscillator. The area of the bioelectrical impedance analysis circuit was remarkably small owing to square waveform current. All circuits were fabricated with a 0.18μm 1P6M standard CMOS technology and occupied an area of 0.43mm^2. The GIDL-controlled ring-oscillator successfully oscillated at the ultralow frequency of 4.3Hz, and the bioelectrical impedance analysis circuit can measure impedance values between 100Ω and 100MΩ.

1. Introduction

In recent years, biosignal recording, tissue stimulation, medical treatment, and disease detection systems have been reported from lots of organizations [1][2]. For high quality and effective biosignal recording, it is necessary to keep stable contacts between tissues and electrodes, and is also necessary to periodically monitor bioelectrical impedances. In order to realize high quality recording and safe electrical stimulation, we have been developing a wide-range impedance analysis circuit [3][4]. In the previous papers, we reported an impedance analysis circuit with square wave current source, which was much smaller than conventional impedance analysis circuits. We showed that it was necessary for precise capacitance measurements to use a low frequency square wave. We also reported that an ultralow current source using gate-induced drain-leakage (GIDL) current generated a quite stable pico-ampere-order current and it can be used as not only a reference current but also an applied current in impedance measurement. In this paper, we developed an ultrasmall current and ultralow frequency square wave generator using GIDL current for precise capacitance measurement, enabling to ultrawide-range impedance measurements.

2. Architecture and Circuit Design

Fig. 1 shows a block diagram of an ultrawide-range multi-channel biosignal acquisition system composed of a bioelectrical impedance analysis circuit and a biosignal recording circuit. The bioelectrical impedance analysis circuit consisted of a voltage measurement circuit (*V-measure*), a current source circuit (*I-source*), an ultralow current source circuit (*I-source(GIDL)*), and an ultraslow ring-oscillator using GIDL current (*RingOsc(GIDL)*). I-source (GIDL) was used to measure hundreds-MΩ-order impedances, and RingOsc(GIDL) was used for the square waveform impedance measurement proposed in the previous paper [3]. As the square waveform impedance measurement circuit did not need both high-resolution DACs and high-order LPFs (Low-Pass-Filter) unlike the conventional sine waveform impedance measurement circuit, the square waveform measurement had a big advantage in area efficiency. In the square waveform impedance measurement, a charge transfer resistance R_{CT} was calculated from amplitude values of input current and measurement voltages. An electrical double layer capacitance C_{DL} was also calculated from a rise delay time. In order to calculate the accurate C_{DL}, it was strongly required for the square waveform current generator to generate an ultralow frequency current. Therefore, we designed a current-starved type ultralow frequency ring-oscillator using GIDL current in the square waveform impedance measurement circuit. The GIDL current was originated from a band-to-band tunneling of electrons and occurred in gate-drain overlap regions during applying of large negative voltages to the gate and positive voltages to the drain [5]. Fig. 2 shows a schematic of ring-oscillator using GIDL current. When Vg was biased to negative voltages, M0 generated GIDL current and the GIDL current was consecutively copied to inverter chains by a current mirror configuration of M1, M2, and M3. As the GIDL current determined the currents of the inverter chain and was as small as pico-ampere-order, the ring-oscillator can operate with ultralow frequencies.

3. Measurement Results

Fig. 3 shows a simulated waveform of the ring-oscillator using GIDL current. The lowest oscillation frequency of 4.3Hz was obtained with the Vg of -0.3V for 17-stages ring-oscillators. Fig. 4 shows resistance measurement results with GIDL-controlled ultrasmall current square wave generator. A current was applied to off-chip resistors from the ultralow current source circuit using GIDL current operated by a timing controller, and the voltages were measured with the V-measure. It was obviously shown that there was linear relationship between off-chip resistances and measured resistances. The measured resistances were slightly larger than the off-chip resistances, which was attributed to leakage currents caused by experimental system. Fig. 5 shows the bioelectrical impedance analysis circuit with GIDL-controlled ultrasmall current square wave generator, which was fabricated with a 0.18μm 1P6M standard CMOS technology. The bioelectrical impedance analysis circuit was composed of V-measure, I-source, and the ultralow current source circuit using GIDL current. The chip area was 0.43mm^2 which was 70% smaller than the previously reported impedance analysis circuit [1].

4. Conclusions

We developed the area-efficient and ultrawide-range bioelectrical impedance analysis circuit including the ultralow current source circuit and ultraslow ring-oscillator based on GIDL current. From the results of function verification using the prototype chip and simulation, it was successfully shown that resistance values of more than 10MΩ was measured with GIDL-controlled ultrasmall current square wave generator. It was also shown that the ultraslow 17-stages ring-oscillator with GIDL current oscillated with a frequency of 4.3Hz for Vg of -0.3V. The bioelectrical impedance analysis circuit with GIDL-controlled ultrasmall current and ultralow frequency square wave generator can be used for various kinds of biomedical applications.

Acknowledgments

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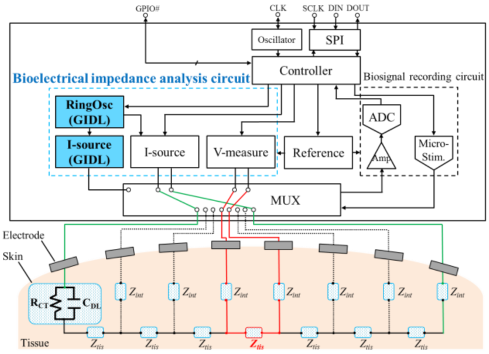

Fig. 1. Block diagram of ultrawide-range multi-channel biosignal acquisition system.

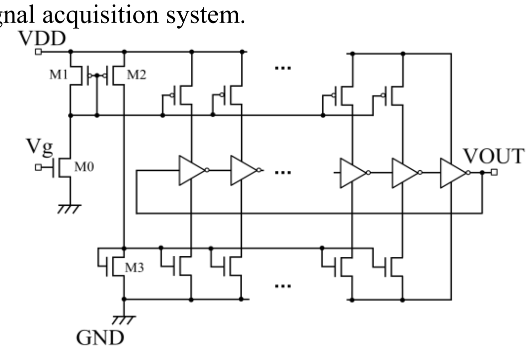

Fig. 2. Schematic of ring-oscillator using GIDL current.

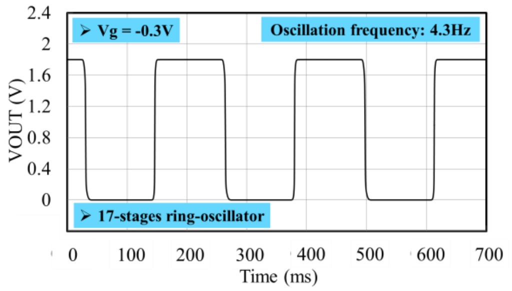

Fig. 3. Simulated waveform of the ring-oscillator using GIDL current.

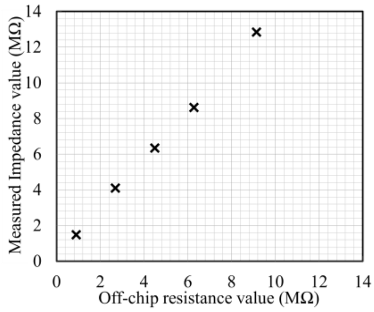

Fig. 4. Impedance measurement result with GIDL-controlled ultrasmall current square wave generator.

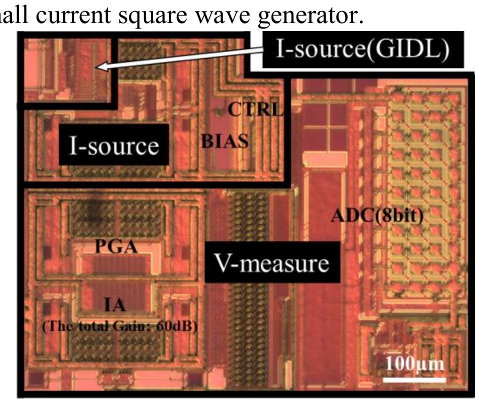

Fig. 5. Chip photograph of bioelectrical impedance analysis circuit with GIDL-controlled ultrasmall current square wave generator.

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